

DOI: 10.1111/1600-0498.12347

**SPECIAL ISSUE ARTICLE****Centaurus** WILEY

# Introduction—Up, down, round and round: Verticalities in the history of science

Wilko Graf von Hardenberg<sup>1</sup>  | Martin Mahony<sup>2</sup> <sup>1</sup>Max Planck Institute for the History of Science, Berlin, Germany<sup>2</sup>University of East Anglia, School of Environmental Sciences, Norwich, UK**Correspondence**

Wilko Graf von Hardenberg, Max Planck Institute for the History of Science, Boltzmannstr. 22, 14195 Berlin, Germany.  
Email: [whardenberg@mpiwg-berlin.mpg.de](mailto:whardenberg@mpiwg-berlin.mpg.de)

**SPECIAL ISSUE**

Verticality in the History of Science

**GUEST EDITOR**

Wilko Graf von Hardenberg and  
Martin Mahony

This Special Issue was selected by a dedicated ESHS committee after a public call for special issues.

**Abstract**

History of science's spatial turn has focused on the horizontal dimension, leaving the role of the vertical mostly unexplored as both a condition and object of scientific knowledge production. This special issue seeks to contribute to a burgeoning discussion on the role of verticality in modern sciences, building upon a wider interdisciplinary debate about the importance of the vertical and the volumetric in the making of modern lifeworlds. In this essay and in the contributions that follow, verticality appears as a condition of knowledge production—a set of movements and mobilities, technical challenges, political negotiations, and bodily hardships—and an object of scientific inquiry, requiring new techniques of mapping and visualisation and generative of new insights into physical processes and temporal change. By foregrounding the vertical, historians of science can gain new insights and tell new stories about how science is done in the field, the observatory, and the laboratory, and about how those sciences have helped build a modern, three-dimensional world.

**KEYWORDS**

environment, field, spatial turn, verticality, volume

This is an open access article under the terms of the Creative Commons Attribution License, which permits use, distribution and reproduction in any medium, provided the original work is properly cited.

© 2020 The Authors. *Centaurus* published by John Wiley & Sons Ltd.

In the last three decades, history of science has experienced a definite and enduring “spatial turn.”<sup>1</sup> While this has been immensely productive of new insights into the materiality and historicity of scientific endeavours, most works have largely focused on the horizontal dimension in which science has been produced and transmitted. In history of science, space has thus mostly been understood as place and location, a matter of coordinates, national or regional boundaries, and territorial extension.<sup>2</sup> In this special issue, we intend to enrich such a flat interpretation of space, building upon a rising discussion about the role of depth and altitude in a new appraisal of science’s spatiality that combines and juxtaposes histories of science in different verticalities. Scientific practices, after all, do not just occur in, and construct, two-dimensional space, but take place in three dimensions. There is likewise a historicity to how science itself has engaged with the vertical plane. We agree here with Michael Reidy, who recently noted that “verticality can give the spatial turn some vitality, some graininess, some needed texture.”<sup>3</sup> As Reidy pointed out earlier, in *Tides of History*, a particular vertical consciousness “engulfed science in the early nineteenth century.”<sup>4</sup> Since then, the sciences of height, depth, and volume have been fundamental to the emergence of the three-dimensional, technologically-mediated world we inhabit. However, despite some notable exceptions, the specifics of these sciences have been largely absent from recent concerns with the spatiality of scientific knowledge. With this special issue, we aim to crystallise emerging conversations across history of science dealing with verticality in science—with verticality featuring both as a material condition of knowledge production and as an object of scientific inquiry in itself.

There is, perhaps, already the stirring of a “vertical turn” underway in history of science: historians have examined the role of science in such diverse ventures into the vertical dimension as can be found in meteorology, astronomy, geology, geodesy, physiology, and oceanography.<sup>5</sup> However, it is arguable that these studies, while providing exhaustive accounts of the history of how the vertical has been determined and measured, have yet to fully take into consideration how the broader concept of the vertical—as well as the peculiar spatial and physical constraints of the specific vertical spaces considered—has influenced how science is produced. This is what we hope to achieve with this special issue: to begin the task of thinking verticality across a range of different histories and case studies, and to start assembling the conceptual and historiographical tools required to comprehend the multiple roles which the vertical plays in different branches of science through the 19th and 20th centuries. We contend that moving the idea of verticality into the foreground—considering it in its full potential—allows historians to go beyond the particularities of discrete cases and to begin to recognise commonalities in how science has reckoned with, thought about, conquered, or been defeated by verticality. In doing so, we aim to answer recent calls for historians of all stripes to pay greater attention to the role of the vertical in historiography.<sup>6</sup> Furthermore, we suggest that by putting verticality at the centre of our analysis of science, new stories can be told about theoretical change, the material practices of knowledge making, the visual culture of science, and more. Attending to the vertical dimension provides a more comprehensive image of the place of science in a three-dimensional world.

In this introductory essay, we situate the subsequent case studies within the context of an expanding interdisciplinary conversation about the verticalities of modern lifeworlds. We draw attention to five aspects which we believe can help delineate and enrich further research in this area: “knowing the vertical,” “vertical politics,” “elemental encounters and the vertical field,” “bodies and technologies,” and “representing the vertical.” We do not claim with this special issue that we are able to cover all possible ways verticality can be conceptualised and understood.<sup>7</sup> But we aim to make a start by drawing out connections with new work in mountain history, environmental history, human geography, and history of technology. Part of our aim is to broaden the attempt made by Bigg, Aubin, and

<sup>1</sup>Ophir & Shapin (1991); Shapin (1998); Smith & Agar (1998); Livingstone (2003); Naylor (2005); Meusburger, Livingstone, & Jöns (2010); Gieryn (2018).

<sup>2</sup>Withers (2009).

<sup>3</sup>Reidy (2017, p. 587).

<sup>4</sup>Reidy (2008, p. 280).

<sup>5</sup>Kohler & Vetter (2016, pp. 287–288). See also Rozwadowski (2001; 2005); Le Gars & Aubin (2009); Barry (1978); Braun (2000); Heggie (2013); Feldman (1985); Fleming, Jankovic, & Coen (2006); Fleming (2016); Bourguet (2002).

<sup>6</sup>Berger Ziauddin (2016).

<sup>7</sup>Other dimensions of the vertical and of how it affects human thought and knowledge production can be easily imagined, such as its figurative role in European medieval thought, its use as a placeholder for hierarchical societal structures in different cultural settings, or its symbolic function within modern psychoanalysis. For examples of scholarly developments in some of these diverse fields, see Ireton & Schaumann (2012); Schregel, Ascuto, & Engelhardt (2020).

Felsch to explain the role of mountains in scientific endeavours, connecting this narrative with a variety of other vertical spaces.<sup>8</sup> In this issue we venture thus not only up mountains, but also in balloons and airplanes and down into caves, mines, drill-holes, and seas. If, as Bigg, Aubin, and Felsch state, “the strategies, resources, and techniques for surviving in this challenging environment are inseparable from the strategies, resources, and techniques for producing knowledge on or about the mountain,” the technologies and methods used to make science along the vertical axis have a crucial impact on how knowledge about the vertical can be produced.<sup>9</sup> For instance, a history of alpine astronomical observatories gains in depth when its connections to the material issues of setting up observatories at high altitude and the role of mountaineering in scouting for the best locations are considered.<sup>10</sup> Likewise, the history of the exploration of oceanic depths might be seen from a different perspective when taking fully into account the connections between different layers of the ocean along the vertical axis—how they have been understood scientifically and navigated practically—not to mention the material connections between the ocean and the layers of atmosphere that sit above it, or the ideological connections between its exploration and that of outer space.<sup>11</sup>

A thorough analysis of the role of verticality can thus contribute to the intensification of the burgeoning dialogue between history of science and environmental history. The potential of the interpretative models of environmental historical scholarship to rejuvenate the way history of science has connected local dimensions with broader and deeper scales, both spatially and temporally, has been noted already by Mitman, Murphy and Sellers.<sup>12</sup> Verticality has the potential to strengthen these connections. The role, for instance, of ecosystems, a crucial dimension of the spatial analysis offered by environmental historians, in framing the production of knowledge only can be understood if the full vertical complexity of territories is taken into consideration. They can, in fact, be comprehended only in three dimensions, as regards both their visualisation and their localization in discrete places. Moreover, landscapes, seascapes, and ecological niches change radically and swiftly along the vertical axis. As such, the ability of the vertical to represent at scale broader biogeographical variations lies at the core of what has been termed Humboldtian science.<sup>13</sup>

Thus, in this special issue, we are interested in how the consciousness of a vertical dimension was developed and appropriated explicitly by the historical actors involved in making science. The vertical indeed represents a much greater and more encompassing dimension than just mountains, the atmosphere, and oceanic depths. As some of our papers here show (Achermann most directly), verticality is not only about doing science at altitude or depth, but also about reading data collected at different altitudes or reading the vertical as a proxy for the temporal, as has long been usual, for instance, in archaeology and stratigraphy.<sup>14</sup> As anthropologist Cristián Simonetti reminds us, “the stratigraphic understanding of time” has affected and shaped a variety of disciplines and interacted with other vertical representations of time, such as the ones adopted in genealogy.<sup>15</sup> It is, in other words, not only about being physically at different heights or depths, but also about looking at the world along the vertical axis.<sup>16</sup> Considering the role of the vertical in history of science thus brings together accounts of expeditions, scientific ventures, and fieldwork in extreme environments; the question of how the senses perceive verticality; the epistemic, technical, and bodily challenges of producing knowledge of vertical spaces; and the history of collecting and visualising data at a distance, through new technologies and the construction of new bird's-eye views. In the following sections, we draw out these key historiographical points, and show how the papers in this special issue address them in their own ways.

<sup>8</sup>Bigg, Aubin, & Felsch (2009). See also Cosgrove & Della Dora (2009).

<sup>9</sup>Bigg, Aubin, & Felsch (2009, p. 314).

<sup>10</sup>See Minor (2020).

<sup>11</sup>See Adler (2020). See also Vollset, Hornes, & Ellingsen (2018, Ch. 5).

<sup>12</sup>Mitman, Murphy, & Sellers (2004).

<sup>13</sup>Dettelbach (1996); Anthony (2018).

<sup>14</sup>Achermann (2020). Simonetti (2014; 2015).

<sup>15</sup>Simonetti (2015, p. 140).

<sup>16</sup>In this regard, see also Braun (2000).

## 1 | KNOWING THE VERTICAL

Knowing the vertical throws up at least two major epistemic challenges. The first connects to the simple challenge of accessibility—how to produce reliable, verifiable knowledge of spaces where direct attestive witnessing is hardly possible? Histories of exploration and of the credibility economies of geographical knowledge are instructive here: “vertical” exploration has been shown to have operated at the intersections of gendered heroics, colonial nationalisms, and diverse forms of knowledge.<sup>17</sup> Historical geographer Boris Michel, for instance, examines the links between geographical knowledge making, mountaineering, and German colonialism in his retelling of Hans Meyer’s late 19th-century “conquest” of Mount Kilimanjaro.<sup>18</sup> Michel shows how overcoming the physical demands of vertical ascent was rendered as a heroic, manly accomplishment for public and political audiences, as well as being a fundamentally national project, with the literal pinnacle of the mountain finding its way back to the desk of Kaiser Wilhelm II, where it sat as a totem of Germany’s growing—outwardly and upwardly—colonial reach. Michel makes plain how these discourses of heroic masculinity and European supremacy combined to render Hans Meyer a reliable and authoritative geographical witness, with the mountain acting as what Thomas Gieryn might call a “truth-spot,” grounding and supporting Meyer’s wider claims about the nature of East African peoples, climates, flora, and fauna.<sup>19</sup> As we explore below, accessibility to the vertical is also crucially mediated by the technical capabilities needed to physically do research along this spatial axis, a fact that, as noted variously throughout the papers collected in this special issue, brings to the forefront the importance of embedding approaches taken from the history of technology into the analysis.<sup>20</sup>

A second major epistemic question relates to the challenge of defining a baseline against which things like elevation and depth might be measured. Like any distance, both are relative measurements. No vertical dimension is, in fact, understandable as such without a reference point where the vertical and horizontal intersect, and where a distinction is made between what is a depth, what our plane of reference, and what a height. The matter of how these reference points have been defined is a fascinating matter of historiographical inquiry that parallels the history of how reference points have been determined on the horizontal plane.<sup>21</sup> Many different kinds of vertical datums have been selected throughout history, defined with increasing degrees of precision. In their earliest incarnations, generic and under-defined “lowest places on earth” were usually adopted as points of reference. On the local scale, more or less arbitrary markers—such as, for instance, a notch in a pillar—were used as the vertical zero.<sup>22</sup> When the level of the sea was taken into consideration for this purpose, it usually was taken at face value as something that could be determined simply by standing by the shore, without any perceived need to define it through measurement.<sup>23</sup> Practicalities and local needs determined the choice of the most appropriate reference point marking the boundary between heights and depths. To put it simply, if our relationship to the sea is, so to speak, defensive, we will be mainly interested in recording the highest high tide, and thus the farthest inland point reached by the sea in its regular movements becomes the reference point. Conversely, nautical chart datums, explicitly intended to facilitate navigation, refer usually to some iteration of average low or lowest low tide, so as to always indicate the minimum available depth of water.

Defining the vertical depended, thus, on the volumetric space that was of most pressing interest: that of the sea’s incursions onto land, or that of the space beneath a ship’s hull. Only from the early 19th century were the theoretical and technical tools developed that allowed for mean sea level to be defined, measured, and adopted widely as the standard vertical datum.<sup>24</sup> Specific needs, however, still call for varying systems of reference. Depth soundings

<sup>17</sup>See, for example, Cosgrove & Della Dora (2009); Naylor & Ryan (2010).

<sup>18</sup>Michel (2019).

<sup>19</sup>Gieryn (2018). On similar processes operating in glaciology, see Carey (2007); Carey, Jackson, Antonello, & Rushing (2016).

<sup>20</sup>See, for instance, Rozwadowski (2001); Gärdebo (2016); Camprubi & Robinson (2016).

<sup>21</sup>For example, see Withers (2017).

<sup>22</sup>Cajori (1929, p. 483); Lallemand (1891, p. 931).

<sup>23</sup>For a brief account of the history of the methods used to assess sea level as an hypsometric baseline, see Hardenberg (2020).

<sup>24</sup>Reidy (2008, pp. 175–79); Hardenberg (2020, pp. 11–13).

typically refer to the surface of the water, assumed to approximate its mean state at high sea. In aviation, multiple heights are considered, both referring to mean sea level and to land, depending on the altitude of flight and whether air pressure or the risk of hitting the ground is more important. On land, for the depths of caves and mines, the surface is usually used as reference and a difference was made, as explained by Humboldt, between the latter—the “absolute depth”—and the “relative depth” compared to sea level.<sup>25</sup> As Herbert Heyde put it in his seminal 1923 work on the vertical datums of European countries, “no altitude reference point is determined once and for all by nature, each depends on being conventionally determined.”<sup>26</sup> To generalise, we could state that all vertical reference points are such in reason of their usefulness, and represent a negotiated socio-technical agreement. For instance, recent attempts at defining, thanks to satellite measurements of mean sea level, a unified global vertical datum show how each reference system may only serve particular needs. While global mean sea level is essential to showcase and describe the vertical movements of the sea in a rapidly changing world, the same would end up being meaningless if applied to any specific point along the world's coasts for the purpose of building an infrastructure; for instance, a civil engineer or a local inhabitant would deem it to be a completely useless piece of information if they were told that the datum of reference—that is, the mean sea level—were located way above their head.<sup>27</sup> The task for historians of science is to attend to negotiations like these and to examine the intertwining of epistemic and social concerns in the making of what might otherwise be considered the banal, technical touchstones of the modern world. Indeed, as an expanding literature on the politics of verticality is showing, scientific and technical practices are often at the heart of struggles to make and unmake three-dimensional worlds.

## 2 | VERTICAL POLITICS

... the vertical is not one of the dimensions of space, it is the dimension of power.  
It dominates, rises up, threatens and flattens. —Michel Foucault<sup>28</sup>

No one, except perhaps levitators, can move vertically on their own, and so sociality and power relationships are central to understanding different verticalities: power furnishes the means of moving beyond the horizontal spaces in which humanity mostly lives, as well as representations of vertical mobility as heroic conquest.<sup>29</sup>

The last two decades have seen an explosion of interest in verticality among human geographers and political scientists. Political geographers in particular have responded to Michel Foucault's passing suggestion that the vertical needs to be understood as a “dimension of power”—or even as *the* dimension of power.<sup>30</sup> A great deal of the inspiration behind this work can be traced to Eyal Weizman's work on the militarised cartographies of the occupied West Bank. In a series of studies, Weizman mapped out how the occupied territories are bounded, ordered, and controlled not just through borders and walls that restrict the horizontal circulation of people and things, but also through a dense network of tunnels, bridges, overlapping roads, underground pipes, and aerial surveillance technologies that, in this case, render two-dimensional maps meaningless as representations of political space.<sup>31</sup> Like in China Miéville's fantasy police procedural *The City and the City*, political territory cannot be reduced to the brightly coloured blocks adorning the walls of primary school geography lessons; rather, territories interlock and overlap, and borders and boundaries in the vertical dimension are as important to understand as those in the horizontal.<sup>32</sup> Weizman

<sup>25</sup>Humboldt (1845, p. 416).

<sup>26</sup>Heyde (1923/1999, p. 3), translation by the corresponding author.

<sup>27</sup>D. Roman (2016, April 5), personal communication.

<sup>28</sup>Foucault (2007, p. 170).

<sup>29</sup>On the history of levitation, see Adey (2017).

<sup>30</sup>Foucault (2007, p. 170).

<sup>31</sup>Weizman (2002; 2007).

<sup>32</sup>Miéville (2009). For instance, on the impact of vertical movements on territorial claims at times of radical anthropogenic environmental change, see Sammler (2019); Ferrari, Pasqual, & Bagnato (2019).

emphasises the role of both political strategy and technical knowledge in constituting territory as three dimensional. Hydrology and geology, for instance, the sciences of the underground, become key resources in claiming and adjudicating the rights of different groups to use on the surface what might be found below. Likewise, he shows how archaeology has been enrolled into the project of claiming territorial rights—the pasts which are sedimented underground serving as new markers of cultural continuity and political sovereignty. The lesson from the West Bank, Weizman suggests, is that territory as a concept needs to be fully reappraised in all its vertical complexity. “The departure from a planar division of a territory to the creation of three-dimensional boundaries across sovereign bulks redefines the relationship between sovereignty and space.”<sup>33</sup>

Weizman's arguments have been taken up in a growing literature on “vertical geopolitics,” which interrogates how political and military actors themselves increasingly see territory as a three-dimensional phenomenon.<sup>34</sup> This strand of work has also taken significant inspiration from histories of the physical sciences. In an influential paper, now two decades old, geographer Bruce Braun succeeded in writing the history of geology into what was at the time an exploding, Foucault-inspired literature on the emergence of modern governmental rationalities and the epistemes that underpinned them.<sup>35</sup> While Foucault had hinted at the importance of the “territory with its qualities,” and a “complex composed of men [sic] and things,” as a target of the emerging problematic of government in the modern state, his own and his acolytes' work focused on the human and social sciences that underpinned new forms of governmentality.<sup>36</sup> Using the case study of 19th-century western Canada, Braun shows how the shift from mineralogy to geology as a way of seeing nature and landscape was directly constitutive of new forms of Canadian political rationality. In part, this was about the straightforwardly instrumental use of the new science of rocks—geological study could help identify new spaces for the accumulation of capital. But in the probabilistic registers in which prospecting was framed and regulated, in educational efforts to produce geological subjects able to see and exploit resources correctly, and in the reform of land laws to accommodate new means of reliably speculating for valuable deposits, the production of geological territory, of a singular national economy, and of an economically productive citizenry went hand in hand. Crucially for our purposes here, Braun describes how geology “rendered the space of the Canadian state vertical.” The land underneath settlers' feet could now be read differently; territory now had depth, which “could be known and represented systematically,” and “in order to optimize use of the nation's 'vertical' territory, property regimes needed to include the internal architecture of the earth.”<sup>37</sup> Braun's arguments are a useful reminder to historians of the physical and natural sciences that the access these disciplines provided to new depths (and heights) of state territory did not just open up new resource frontiers, but also constituted new ways of thinking about and seeing the relationships between state, population, economy, and territory. For Braun, verticality, as an epistemic accomplishment, was central to the emergence not just of modern science, but of the modern state as well.<sup>38</sup>

Environmental historians have likewise begun to adopt a wider “vertical turn” to reframe traditional historiographies. Endfield and Van Lieshout have, for instance, recently written about how “vertical conceptualisations of space” played a crucial role in redefining the legal framework around early modern mines.<sup>39</sup> Jason Moore has discussed how the culturally grounded conflict between a vertical and horizontal organisation of the economic system and their different interaction with Andean ecosystems affected political ecologies of the area in the early modern age.<sup>40</sup> Another aspect of huge interest from a legal historical perspective is, more generally, how property and control are understood in the vertical dimension in oceans and the atmosphere.<sup>41</sup>

<sup>33</sup>Weizman (2002, Ch. 2).

<sup>34</sup>Graham (2004); Gregory (2011); Shaw (2016); Kindervater (2017).

<sup>35</sup>Braun (2000).

<sup>36</sup>Foucault (1991, p. 94).

<sup>37</sup>Braun (2000, pp. 28, 34).

<sup>38</sup>In this regard, see also Melo Zurita & Munro (2019).

<sup>39</sup>Endfield & Van Lieshout (2020, p. 1).

<sup>40</sup>Moore (2010).

<sup>41</sup>See Steinberg (2001) and Banner (2008) for introductions to the issue.

The emphasis on seeing vertically figures prominently in work on how the rise of aviation afforded new ways of both controlling and attacking territory. As the editors of the volume “From Above: War, Violence and Verticality” put it, “Being able to see and reach down from the aeroplane’s platform has clearly permitted entirely new and violent cultural practices that have transformed the world below.” The studies collected in the volume show “how the techniques of government flown from the skies have brought populations into the terrain of state legibility and security so that they might become governable subjects.”<sup>42</sup> In the emergence and development of new techniques of map-making, such as aerial survey and photogrammetry, we can see how “the view from the air” has been, and continues to be, deeply “complicit in producing, sustaining and eroding territorial sovereignty on the ground below.” Examining the relationship between an aerial viewpoint and the conduct of war, the authors emphasise the aerial view not as something “weightless, ungrounded and light,” but as a contingent and unstable product of grounded infrastructures, tumultuous elemental encounters and complex sociotechnical networks.<sup>43</sup> “Verticality, it seems, does not equal automatic and sure-footed sight.”<sup>44</sup> The task of the historian, whether of warfare or of science, is not simply to map the political consequences of the view from above; the achievement of verticality itself is something that requires explanation.

### 3 | ELEMENTAL ENCOUNTERS AND THE VERTICAL FIELD

In an influential paper of 2013, Stuart Elden contended that attending to the politics of verticality involves unhelpful abstractions of how power and knowledge work through space; in the relationship between space and security, a situation like that of the West Bank cannot be understood along a simple axis of up and down, but rather demands a more rounded focus on “volume.”<sup>45</sup> Playing on what one might hear over police radios during an emergency—“secure the area”—Elden suggests that contemporary forms of power respond to a call to “secure the volume.” Territory does not just work horizontally or vertically, but is a fully three-dimensional thing, as reflected, for example, in no-fly zones or in Weizman’s observations about the politics of subterranean territory and resources in the West Bank. Drawing inspiration from Sloterdijk’s spherology, Elden builds on his own work on the fate of territoriality in the War on Terror, in which he argued that:

Recognizing the vertical dimension of territory shows that territory is a volume rather than an area, and noting that lines on maps have only a limited height when translated into lines on the ground showcases a new level of vulnerability: a vulnerability to imagined senses of a protected territory, the body of the state.<sup>46</sup>

Elden’s call to think geopolitics in terms of volume has been heeded by many, but has also been critiqued for its own tendency towards abstraction and to its privileging of a topographical imagination of spatial boundedness and fixity.<sup>47</sup> Elaine Campbell seeks to develop a more topological account of security, pointing out that for Foucault—that recurring figure in these debates—security is achieved not through fixing limits and boundaries, but by guaranteeing circulations of people and matter.<sup>48</sup> Campbell proposes that revisiting Foucault’s notion of milieu can help us to think through how security is not just about securing volumetric space, but also about securing tangles of human–nonhuman relations. In thinking about securitisation, the notion invites us:

<sup>42</sup>Adey, Whitehead, & Williams (2013, p. 3).

<sup>43</sup>Adey (2017, p. 7).

<sup>44</sup>Adey (2017, p. 8).

<sup>45</sup>Elden (2013).

<sup>46</sup>Elden (2009, p. xxii). See, for example, Sloterdijk (2016).

<sup>47</sup>For an example where the volumetric take has been adopted, see Melo Zurita & Munro (2019). For a critique, see Steinberg & Peters (2015).

<sup>48</sup>Campbell (2019).

to look beyond the urban to the elsewhere and otherwise of securitisation—to coastal, oceanic, rural, remote, subterranean, aerial settings—where “making secure” is pivotal on the geophysical and material dynamics of space and their (sometimes unanticipated) co-articulation with circulations of aerial, hydrospheric and terrestrial technologies, and human practices.<sup>49</sup>

Likewise, Maria Pérez, writing about a very different context (a Venezuelan caving society), argues that the notion of verticality, as opposed to volume, “resonates with a more ‘open-ended’ and boundless approach to space,” allowing the historian or the ethnographer to attend to space not just as a series of areas or volumes to be controlled, but as a lively realm of emergent relations and entanglements between humans and the elements.<sup>50</sup>

Historians of science have much to say about how these relations and entanglements have been understood by historical actors, and made legible to those who would seek to either exploit or protect them. The notion of verticality can help foreground these entanglements, but we are also alive to the problem that verticality can imply—ironically—a rather one-dimensional, up-and-down view of space in scientific practice. In certain cases, the notion of volume is more resonant and useful. Some of the papers that follow examine verticality and/or volume as actors’ categories; others use them as conceptual tools which can open up new analyses of what may otherwise be quite well-known and taken-for-granted stories of scientific change and discovery. We are not interested in settling conceptual arguments about whether verticality or volume is the best means of analysing the social world in three dimensions, but rather in how these concepts can shed new light on how a three-dimensional social and natural world has been constructed, negotiated, and experienced by historical actors.

### 3.1 | The vertical field

The literature on field sciences has already shown how important the historical geography of science has been in clarifying the role of space and location in the processes through which knowledge is produced.<sup>51</sup> Increasingly, the field is being analysed as a three-dimensional space, as Kohler and Vetter have recently pointed out:

Verticality is a key emerging concept for thinking about place in the field. Whereas a horizontal view takes students of place across airy landscapes of towns, forests, farms and ranches, the vertical view upward or downward takes us away from human habitation into depths and heights in which no one lives (for long) yet which are vital to global economy and polity.<sup>52</sup>

Kohler and Vetter emphasise the role of mobility in the construction and enactment of the field. This may be particularly true of sciences that deal with phenomena in the vertical; in sciences such as meteorology, for instance, the object of study is highly mobile and may be more or less independent of the horizontal landscapes from which a field site may be carved out.<sup>53</sup> The field becomes something of a movable feast, and can thus be considered “a category of people and things in place *and* in motion.”<sup>54</sup>

The papers by Patrick Anthony and Matthew Henry both show the vertical field to be constituted by combinations of stasis and movement. For Anthony, the distinctive forms of vertical mobility that were formative for Alexander von Humboldt’s vertical consciousness were tied to Humboldt’s experiences as a mining official, while his later work visualising vertical patterns and relationships is a further illustration, following Braun, of how science and

<sup>49</sup>Campbell (2019, p. 17).

<sup>50</sup>Pérez (2015, p. 5). See also below for a more detailed discussion of Pérez’s work.

<sup>51</sup>Kohler (2011); Vetter (2011); Livingstone (2003).

<sup>52</sup>Kohler & Vetter (2016, pp. 287–288).

<sup>53</sup>See Reidy (2010); Fleming (2016); Coen (2018); Henry (2020).

<sup>54</sup>Kohler & Vetter (2016, p. 286), original emphasis.



industry interacted to produce new ways of seeing in three dimensions.<sup>55</sup> Matthew Henry's analysis of the emergence of a three-dimensional approach to aviation meteorology in interwar New Zealand, founded on the repetitious movement of instruments and data between ground and upper atmosphere, likewise emphasises the intersection of science and commerce in the making of new vertical spatialities.<sup>56</sup> Back under the ground, Johannes Mattes analyses the development of speleology as a new disciplinary formation, and unpicks how caves functioned as a particular kind of field site where multiple forms of knowledge and competing political claims could coalesce.<sup>57</sup> Mattes shows how the development of surveying techniques allowed an organised speleology to emerge alongside a newly vertical conception of territory in central Europe, where the waxing and waning of empires played out amid competing claims about what national stories the subterranean could reveal as a storehouse of both natural and cultural heritage.

A number of the papers explicitly aim at understanding the conditions of possibility that enable looking at the world along the vertical axis. Adriana Minor's paper examines this in terms of the transnational circulation of knowledge and technology, while Michael Reidy and Patrick Anthony both show how the vertical consciousness of Darwin and Humboldt was shaped by the affordances of expeditionary science, and also by their engagements with the vertical and volumetric environments of mountains, caves, mines, and the sea.<sup>58</sup> Dania Achermann likewise illustrates how the vertical affordances of certain technologies of verticality—such as oil drilling—enabled epistemic revolutions to take place in disciplines like climate science, as ice was dug up in the field and freighted to laboratories to be transformed into an archive of climatic change.<sup>59</sup> Anthony Adler highlights the role of both geopolitics and public awareness in creating the framework within which certain forms of scientific activity in the vertical become feasible.<sup>60</sup> But the conditions of possibility of a vertical viewpoint can also be functions of chance, as Paul Merchant shows in his recounting of a number of episodes wherein a new vertical view of a phenomenon was achieved apparently not through high technology and careful planning, but through happy coincidence and happenstance.<sup>61</sup> In his intervention, Merchant explores, through a refined analysis of his oral historical sources, how far this impression is a reflection of historical facts or, rather, a product of the memory and rhetorical stances of his witnesses.

Beside the hardship and the technical mastery commonly needed to explore vertical spaces in the field sciences, both over- and underground and at sea, in extreme conditions the vertical compels a certain degree of separation between the observer and the observed, in which direct observation can become impossible; or, as Merchant shows in his retelling of the discovery of seafloor spreading, vertical distance can provide an ability to better separate signal and noise. Likewise, Staffan Bergwik shows how Sven Hedin purposefully sought a distanced overview of Himalayan mountainscapes in order to read orographic order from apparent chaos.<sup>62</sup> However, when scientists move beyond or through the borders of what has been termed the "critical zone"—the vertical space in which human life is possible—vertical distance often means detachment.<sup>63</sup> In the case of oceanic depths, and likewise for the high atmosphere, remote investigation and analysis by proxy has been crucial in tackling research in vertical spaces.<sup>64</sup> This has led to a commonality of extreme vertical spaces: as Rozwadowski shows for oceanic depths, these kinds of research become possible and comprehensible only "through the mediation of technology."<sup>65</sup> Even in less extreme vertical spaces, technology plays a crucial role in allowing humans to physically access and observe them.<sup>66</sup>

<sup>55</sup>Anthony (2020); Braun (2000).

<sup>56</sup>Henry (2020).

<sup>57</sup>Mattes (2020).

<sup>58</sup>Minor (2020); Reidy (2020).

<sup>59</sup>Achermann (2020).

<sup>60</sup>Adler (2020).

<sup>61</sup>Merchant (2020).

<sup>62</sup>Bergwik (2020).

<sup>63</sup>Latour (2014).

<sup>64</sup>Höhler (2002); Fleming (2016).

<sup>65</sup>Rozwadowski (2001, p. 217).

<sup>66</sup>Pérez (2015).

It is also important to consider the role the vertical plays in science beyond the field: how, for instance, does the vertical influence lab science?<sup>67</sup> How does it inform the processes through which science represents the world? What are the implicit limits of a vertical dimension of science? In this special issue we try to offer approaches that may help to answer such questions, and ask explicitly what is the peculiar role of vertical spatial variations in how science is practiced. What we aim to do is to go beyond a rather traditional history of the mountain sciences and to compare different ways that have been historically relevant in tackling scientific endeavours at different heights and depths. Following up on the broader literature on the spatial dimensions of science, we construe space here both as physical environment and social construct.<sup>68</sup> This plays out in Adriana Minor's history of cosmic-ray physics in Latin America, in which she explores constructions of height and depth in efforts to find the ideal field and observatory sites for this new branch of physics. In so doing, she explores how and why certain locations in Latin America became marked out as ideal sites for science, and how these moves were bound up with geopolitics. Minor's paper thus speaks to how our collective interests here are oriented both towards how the physical dimension of the vertical has historically affected the ways in which science is produced, and how the social aspects of the vertical—the way it is seen, perceived, and represented—frame its reception in knowledge production.

#### 4 | BODIES AND TECHNOLOGIES

The production of vertical knowledge, or the production of knowledge in a vertical dimension, has frequently been contingent upon intersections of body, technology, and inhospitable milieux. As Vanessa Heggie has recently shown, 20th-century efforts to explore and study the most extreme borderlands of the critical zone drove a field-based transformation in the life sciences, as new insights were developed into the behaviour of human bodies in the most testing environments. As scientists and explorers constantly sought the “higher and colder,” the human body became not just a means of seeing and measuring environments, but also an experimental object.<sup>69</sup> The entanglement of bodies and environments, and the technologies that mediated, regulated, or measured that entanglement, is a key theme running through existing work on verticality in science, whether in the context of mountain, cave, or oceanic or atmospheric environments. There is potential here to link work in history of science with arguments emerging in geography and cognate disciplines, and alluded to above, about how attending to vertical (or volumetric) spaces draws attention to the entanglements of human sociotechnical systems with the lively elemental milieux in which they are embedded, or which they seek to enter, dominate, or control.<sup>70</sup> This is a task taken up by a number of our contributors. For example, Staffan Bergwik's paper shows how the bodily suffering and discipline of Swedish geographer Sven Hedin was key not only to the generation of new knowledge about Himalaya, but also to the securing of credibility for his epistemic and narrative strategy of the overview as a new means of seeing, mapping, and interpreting volumetric landscapes. Meanwhile, Anthony Adler discusses in his contribution how the desire to research human endurance in extreme environments was pivotal in the Canadian low-budget ventures into the development of underwater habitats and the idea that they would ultimately contribute to the enhancement of the human body. Venturing into extreme environments has not just been about the vertical expansion of spatial knowledge; it has also been, for some, a prefiguration of a possible post- or trans-human future.

Adey's pioneering work on the rise of “aerial life” has shown how bodies, technologies, and environments have been transformed through the conquest—or perhaps more precisely the production—of airspace.<sup>71</sup> This has fed into emerging work on historical and contemporary cultures of aerial (and vertical) mobility, as well as work from a variety of new materialist traditions on the entanglement of affects and imaginations with the very material characteristics

<sup>67</sup>Kuklick & Kohler (1996).

<sup>68</sup>Finnegan (2008, p. 384).

<sup>69</sup>Heggie (2019).

<sup>70</sup>Campbell (2019).

<sup>71</sup>See, respectively, Adey (2010); Millward (2007).

and affordances of air, atmosphere, and atmospheric technologies.<sup>72</sup> The cultural geographer Derek McCormack, for example, has urged attention to the coevolution of atmospheric science and mobility, and of sensuous and epistemic modes of engaging with air.<sup>73</sup> A series of studies on the mutual shaping of affective and meteorological atmospheres through balloon flights complements historians' interest in the balloon as both vehicle and instrument of scientific discovery.<sup>74</sup> As with mountain climbing, caving, and diving, 18th- and 19th-century ballooning required negotiating the boundary between heroic adventuring and cool-headed science in efforts to enrol allies, reconciling the often contradictory registers of "natural-philosophical investigation and spectacular public performance."<sup>75</sup> Ballooning reminds us that verticality provides not just a view from above, but also a new view of the (usually male) scientist or the adventurer from below:

Most who actively participated in the practice of ballooning were stuck on the ground looking up at the balloon, themselves overlooked by armed guards who would enforce their orderly compliance with the aerostatic performance.<sup>76</sup>

In looking up, viewers might see a new emancipation from terrestrial limits: "a utopian vision that promised a new social order and forecast man's control over nature from his new position in the upper atmosphere," whether in the form of scientific exploration or industrial aerostatic transport.<sup>77</sup> However, the failure of such visions to materialise meant that the balloon soon became a metaphor for frippery and distraction, a useful reminder that the cultural careers of technologies of verticality can be far removed from promises of control and mastery.

The later discovery of the tropopause, the point at which the troposphere shades into the stratosphere and where the relation between temperature and height is inverted, was likewise a story of conjoined epistemic, technical, and bodily challenges. Early balloon voyages into the rarefied air of the upper troposphere often resulted in unconsciousness (or worse), while Teisserenc de Bort's early instrumental readings of a temperature inversion were dismissed as a measurement error—the new technologies of aerology not yet being fully trusted as remote witnesses of the qualities of the upper air.<sup>78</sup> De Bort gained confidence in the readings at the same moment as German meteorologist Richard Assmann published his own findings on the vertical layering of the atmosphere, using instruments he had developed with airship designer Rudolf Hans Bartsch von Sigsfeld. Assmann's and de Bort's co-discovery of the troposphere illustrates the tight coupling of the epistemic and the technological in the sciences of the vertical, with the vertical structuring of the atmosphere coming into view at the moment it became a new space of human mobility. In the 1920s, work began on developing instruments that could broadcast measurements back to the surface of the earth as they were carried into the atmosphere, either tethered to balloons or patched onto aeroplanes, thus getting round the problem of many balloon-borne instruments simply going missing.<sup>79</sup> Matthew Henry's contribution shows how the challenges of measuring and visualising the upper atmosphere took a particular form in interwar New Zealand, and examines how the production of the atmosphere as an "infrastructural space" transformed both the spatiality and the temporality of meteorological work as aviation pushed new demands for real-time information onto weather forecasters. Henry's work is a reminder that we need to add geographical texture to our understanding of the 20th-century emergence of a "vast machine" of geophysical observation, as well as to track how technologies of vertical colonisation, such as the radio-sonde, moved across scientific and technological disciplines to form the infrastructures of globalised life.<sup>80</sup>

<sup>72</sup>See Cwerner (2006); McCormack (2009); Jackson & Fannin (2011); Adey (2015).

<sup>73</sup>McCormack (2008, 2018). See also Adey (2014).

<sup>74</sup>Tucker (1996); Höhler (2001); Doherty (2017).

<sup>75</sup>Doherty (2017, p. 229).

<sup>76</sup>Doherty (2017, p. 247).

<sup>77</sup>Doherty (2017, p. 247).

<sup>78</sup>Hoinka (1997).

<sup>79</sup>Fleming (2016).

<sup>80</sup>Edwards (2010).

It is also important to attend to how technologies of verticality have been repurposed for alternative, decolonial political projects. Turning to the underground, Pérez examines how recent Venezuelan speleology has repurposed the tools of upwards vertical exploration for the project of exploring and mapping the country's unique limestone caves.<sup>81</sup> Contrary to Meyer's colonial example, Pérez shows how "a diverse group of serious amateurs/scientists/explorers" sought to develop an anti-colonial practice of subterranean exploration, embracing a "minimalist ethic" that distanced them from the traditions of the colonial expedition while also avoiding the trappings of excessive technology and equipment, which marked out some areas of caving and climbing as modes of consumption rather than modes of exploration and discovery.<sup>82</sup> The leftist national project of the Venezuelan Speleological Society positioned "cave exploration as a sensuous practice devoid of the male heroics that typifies other adventure and field science pursuits," and as a practice sitting somewhere in between the conventionally opposed categories of sport and science.<sup>83</sup>

## 5 | REPRESENTING THE VERTICAL

Pérez's work is a reminder of the performance dimensions of vertical science, and of the importance of representation in shaping both scientific knowledge and identities. All of the papers that follow address in some way how the vertical dimension has been represented in modern science, whether visually or textually. For instance, both Bergwik and Merchant show the different ways in which the vertical aspects of scientific practice are narrated for different audiences. It has long been acknowledged that verticality has played a crucial role in the history of visualisations in the modern sciences, with the visual representation of altitude-determined climate zones by Humboldt, or Matthew Fontaine Maury's first profiles of the oceanic depths, functioning as famous examples of the transformation of scientific vision. Likewise, the stratigraphic column played an early role in depicting the ages of the earth along a spatial, vertical axis.<sup>84</sup> In more recent times, this geological praxis has developed into a more complex and encompassing practice, in which deep time is reconstructed from data taken from vertical corings of rock, ice, and mud. As Achermann's paper shows, paleoclimatology has become a central and consequential part of this process of seeing time by seeing vertically.<sup>85</sup>

Processes of reconstructing a view from above only on the basis of the data available on the ground lie at the heart of most past cartographic works and geodetic practices.<sup>86</sup> Well before aerial surveys became a reality, between the late 19th and the early 20th centuries it was common to attempt to lift the observer way above the level of the sea to depict and represent the underlying landscapes, as illustrated in Bergwik's analysis of Sven Hedin's efforts to achieve, personally, an overview of Himalaya. Such a procedural approach is at its core an attempt at moving along the vertical axis and producing a visual estimation of how landscapes look from above. Just like the western navigator characterised by cognitive scientist Edwin Hutchins in his fascinating study of the cognition of navigation, scientists have, throughout late modernity, constructed a series of virtual perspectives along the vertical axis "that can never be achieved from any actual viewing point."<sup>87</sup> These developments were part of attempts to create a holistic view of global phenomena that stemmed from Humboldtian science—an effort which, as Patrick Anthony argues here, was imbued with a vertical consciousness, which can itself be traced back to Humboldt's early experiences of mobility along a vertical plane, whether ascending mountains or descending into mines.<sup>88</sup>

<sup>81</sup>Pérez (2015).

<sup>82</sup>Pérez (2015, p. 244).

<sup>83</sup>Pérez (2015, p. 230). See also Pérez & Melo Zurita (2020).

<sup>84</sup>Rupke (1998).

<sup>85</sup>See also Rosol (2015); Antonello & Carey (2017).

<sup>86</sup>Monmonier (2008); Dyce (2013).

<sup>87</sup>Hutchins (1995, p. 108).

<sup>88</sup>Reidy & Rozwadowski (2014).

Papers in this issue address this by exploring, in innovative ways, how vertical data have materially been reread and interpreted as timelines in modern science. In particular, Achermann's paper captures this moment of transformation in the development of a deep-time perspective on glacier development and climatic change, while Reidy shows how Darwin transformed his volumetric viewpoint of South American landscapes into a way of inferring temporal change. And recalling Weizman's work on how the subterranean has been used to claim cultural continuity amid contestation over territorial sovereignty, Mattes shows how caves were reinterpreted as archives of human history, in which what he calls "the vertical order of horizontal layers" could be used as scientific evidence.

Beyond the field site, the expedition route, and the laboratory, verticality in the 20th century became a central element of public imaginaries. Going well beyond the thrill of mountaineering expeditions, new technological marvels allowed people to reach and occupy new vertical locations, through blimps, airplanes, submersibles, and satellites; an occupation of space that was also materially signalled through monuments such as the Eiffel Tower and then through the radical vertical transformation of cityscapes.<sup>89</sup> To scale great heights, whether in an aeroplane or an elevator, became a marker of one's embrace of modernity and often a reinforcement of class divisions, as Lang's *Metropolis* reminds us, before eventually becoming a decidedly banal part of modern life.<sup>90</sup> Moreover, the steady colonisation of the vertical by humans and their instruments has contributed to improving the legibility of the world and to knowing the complex interconnections of its component parts, and has helped birth "an understanding of the world as a geoengine that can be altered, modified, and engineered on a global scale."<sup>91</sup> Understanding this transformation, both from the standpoint of the present and through the concepts of verticality and volume employed by historical actors, is, we would argue, central to deepening our understanding of how science is shaped by space, and of how science has helped make the modern world.

## ACKNOWLEDGEMENTS

This special issue is the product of two panels organised at the International Conference of Historical Geographers 2018 in Warsaw and the 2018 meeting of the European Society for the History of Science in London, respectively. We want to thank the participants and attendees of both events for their comments and feedback, as well as Department 3 of the Max Planck Institute for the History of Science for having generously hosted an authors' workshop in the summer of 2019 that has contributed immensely to shaping this introduction. Open access funding enabled and organized by Projekt DEAL.

## ORCID

Wilko Graf von Hardenberg  <https://orcid.org/0000-0002-8704-6997>

Martin Mahony  <https://orcid.org/0000-0002-6377-413X>

## REFERENCES

- Achermann, D. (2020). Vertical glaciology: A second discovery of the third dimension in climate research. *Centauros*, 62(4), 720–743.
- Adey, P. (2010). *Aerial life: Spaces, mobilities, affects*. Oxford, England: Wiley-Blackwell.
- Adey, P. (2014). *Air: Nature and culture*. London, England: Reaktion.
- Adey, P. (2015). Air's affinities: Geopolitics, chemical affect and the force of the elemental. *Dialogues in Human Geography*, 5(1), 54–75.
- Adey, P. (2017). *Levitation: The science, myth and magic of suspension*. London, England: Reaktion Books.
- Adey, P., Whitehead, M., & Williams, A. (2013). Introduction: Visual culture and verticality. In P. Adey, M. Whitehead, & A. Williams (Eds.), *From above: War, violence and verticality* (pp. 1–18). London, England: Hurst.
- Adler, A. (2020). Deep horizons: Canada's underwater habitat program and vertical dimensions of marine sovereignty. *Centauros*, 62(4), 763–782.

<sup>89</sup>Graham (2016).

<sup>90</sup>Bernard (2014); Pommer & Lang (1927).

<sup>91</sup>Yusoff (2013, p. 2806).

- Anthony, P. (2018). Mining as the working world of Alexander von Humboldt's plant geography and vertical cartography. *Isis*, 109(1), 28–55.
- Anthony, P. (2020). Mines, mountains, and the making of a vertical consciousness in Germany ca. 1800. *Centaurus*, 62(4), 612–630.
- Antonello, A., & Carey, M. (2017). Ice cores and the temporalities of the global environment. *Environmental Humanities*, 9(2), 181–203.
- Banner, S. (2008). *Who owns the sky? The struggle to control airspace from the Wright brothers on*. Cambridge, MA: Harvard University Press.
- Barry, R. G. (1978). H.-B. de Saussure: The first mountain meteorologist. *Bulletin American Meteorological Society*, 56(6), 702–705.
- Berger Ziauddin, S. (2016). Unten ist das neue Oben: Warum der Untergrund im 21. Jahrhundert zur ultimativen Ressource avanciert und die Geschichtswissenschaft gut daran täte, diesen "vertical turn" nicht zu verpassen. *Etü*, (2), 12–15. Retrieved from [https://www.hist.unibe.ch/unibe/portal/fak\\_historisch/dga/hist/content/e11168/e540015/e713494/pdfUntenistdasneueoben\\_ger.pdf](https://www.hist.unibe.ch/unibe/portal/fak_historisch/dga/hist/content/e11168/e540015/e713494/pdfUntenistdasneueoben_ger.pdf).
- Bergwik, S. (2020). Elevation and emotion: Sven Hedin's mountain expedition to Transhimalaya, 1906–1908. *Centaurus*, 62(4), 647–669.
- Bernard, A. (2014). *Lifted: A cultural history of the elevator*. New York, NY: New York University Press.
- Bigg, C., Aubin, D., & Felsch, P. (2009). Introduction: The laboratory of nature—Science in the mountains. *Science in Context*, 22(3), 311–321.
- Bourguet, M.-N. (2002). Landscape with numbers. Natural history, travel and instruments in the late eighteenth and early nineteenth centuries. In M.-N. Bourgeut, C. Licoppe, & H. O. Sibum (Eds.), *Instruments, travel and science: Itineraries of precision from the seventeenth to the twentieth century* (pp. 96–125). London, England: Routledge.
- Braun, B. (2000). Producing vertical territory: Geology and governmentality in late Victorian Canada. *Cultural Geographies*, 7(1), 7–46.
- Cajori, F. (1929). History of determinations of the heights of mountains. *Isis*, 12(3), 482–514.
- Campbell, E. (2019). Three-dimensional security: Layers, spheres, volumes, milieus. *Political Geography*, 69, 10–21.
- Camprubi, L., & Robinson, S. (2016). A gateway to ocean circulation. Surveillance and sovereignty at Gibraltar. *Historical Studies in the Natural Sciences*, 46(4), 429–459. <https://doi.org/10.1525/hsns.2016.46.4.429>
- Carey, M. (2007). The history of ice: How glaciers became an endangered species. *Environmental History*, 12, 497–527.
- Carey, M., Jackson, M., Antonello, A., & Rushing, J. (2016). Glaciers, gender, and science: A feminist glaciology framework for global environmental change research. *Progress in Human Geography*, 40(6), 770–793.
- Coen, D. R. (2018). *Climate in motion: Science, empire, and the problem of scale*. Chicago, IL: University of Chicago Press.
- Cosgrove, D. E., & Della Dora, V. (Eds.). (2009). *High places: Cultural geographies of mountains, ice and science*. London, England: I. B. Tauris.
- Cwerner, S. B. (2006). Vertical flight and urban mobilities: The promise and reality of helicopter travel. *Mobilities*, 1(2), 191–215.
- Dettelbach, M. (1996). Humboldtian science. In N. Jardine, J. A. Secord, & E. C. Spary (Eds.), *Cultures of natural history* (pp. 287–304). Cambridge, England: Cambridge University Press.
- Doherty, C. R. (2017). "Transporting thought": Cultures of balloon flight in Britain, 1784–1785. *The British Journal for the History of Science*, 50(2), 229–247.
- Dyce, M. (2013). Canada between the photograph and the map: Aerial photography, geographical vision and the state. *Journal of Historical Geography*, 39(January), 69–84.
- Edwards, P. N. (2010). *A vast machine: Computer models, climate data, and the politics of global warming*. Cambridge, MA: MIT Press.
- Elden, S. (2009). *Terror and territory: The spatial extent of sovereignty*. Minneapolis, MN: University of Minnesota Press.
- Elden, S. (2013). Secure the volume: Vertical geopolitics and the depth of power. *Political Geography*, 34, 35–51. <http://dx.doi.org/10.1016/j.polgeo.2012.12.009>.
- Endfield, G. H., & Van Lieshout, C. (2020). Water and vertical territory: The volatile and hidden historical geographies of Derbyshire's lead mining soughs, 1650s–1830s. *Geopolitics*, 25(1), 65–87.
- Feldman, T. S. (1985). Applied mathematics and the quantification of experimental physics: The example of barometric hypsometry. *Historical Studies in the Physical Sciences*, 15(2), 127–195. <https://doi.org/10.2307/27757551>
- Ferrari, M., Pasqual, E., & Bagnato, A. (2019). *A Moving Border: Alpine Cartographies of Climate Change*. New York, NY: Columbia University Press.
- Finnegan, D. A. (2008). The spatial turn: Geographical approaches in the history of science. *Journal of the History of Biology*, 41(2), 369–388.
- Fleming, J. R. (2016). *Inventing atmospheric science: Bjerknes, Rossby, Wexler, and the foundations of modern meteorology*. Cambridge, MA: MIT Press.

- Fleming, J. R., Jankovic, V., & Coen, D. R. (Eds.). (2006). *Intimate universality*. Sagamore Beach, MA: Science History Publications.
- Foucault, M. (1991). Governmentality. In G. Burchell, C. Gordon & P. Miller (Eds.), *The Foucault effect* (pp. 89–104). Hemel Hempstead: Harvester Wheatsheaf.
- Foucault, M. (2007). The force of flight. In J. W. Crampton & S. Elden (Eds.), *Space, knowledge and power: Foucault and geography* (pp. 169–172). London, England: Routledge. (Original work published 1973).
- Gärdebo, J. (2016, November 15). Technosphere verticality. *Technosphere Magazine*. Retrieved from <https://technosphere-magazine.hkw.de/p/Technosphere-Verticality-cJSZntQ5B1FVnGxQsh2htg>
- Gieryn, T. F. (2018). *Truth-spots: How places make people believe*. Chicago, IL: University of Chicago Press.
- Graham, S. (2004). Vertical geopolitics: Baghdad and after. *Antipode*, 36(1), 12–23.
- Graham, S. (2016). *Vertical: The city from satellites to bunkers*. London, England: Verso.
- Gregory, D. (2011). From a view to a kill: Drones and late modern war. *Theory, Culture & Society*, 28(7–8), 188–215.
- Hardenberg, W. G. v. (2020). Measuring zero at sea: On the delocalization and abstraction of the geodetic framework. *Journal of Historical Geography*, 68, 11–20. <http://dx.doi.org/10.1016/j.jhg.2019.12.004>.
- Heggie, V. (2013). Experimental physiology, everest and oxygen: From the ghastly kitchens to the gasping lung. *The British Journal for the History of Science*, 46(1), 123–147.
- Heggie, V. (2019). *Higher and colder: A history of extreme physiology and exploration*. Chicago, IL: University of Chicago Press.
- Henry, M. (2020). Making weather vertical: Meteorology and the temporalities of infrastructural atmospheres in New Zealand, ca. 1920–1950. *Centauro*, 62(4), 744–762.
- Heyde, H. (1999). *Die Höhennullpunkte der amtlichen Kartenwerke der europäischen Staaten und ihre Lage zu Normal-Null*. Dortmund, Germany: Förderkreis Vermessungstechn Museum. (Original work published 1923).
- Höhler, S. (2001). *Luftfahrtforschung und Luftfahrtmythos: wissenschaftliche Ballonfahrt in Deutschland, 1880–1910*. Frankfurt, Germany: Campus.
- Höhler, S. (2002). Depth records and ocean volumes: Ocean profiling by sounding technology, 1850–1930. *History and Technology*, 18(2), 119–154.
- Hoinka, K. P. (1997). The tropopause: Discovery, definition and demarcation. *Meteorologische Zeitschrift*, 6(6), 281–303.
- Humboldt, A. von. (1845). *Kosmos. Entwurf einer physischen Weltbeschreibung* (Vol. 1). Stuttgart, Germany: J. G. Cotta'scher Verlag.
- Hutchins, E. (1995). *Cognition in the wild*. Cambridge, MA: MIT Press.
- Ireton, S., & Schaumann, C. (Eds.). (2012). *Heights of reflection: Mountains in the German imagination from the middle ages to the twenty-first century*. Rochester, NY: Camden House.
- Jackson, M., & Fannin, M. (2011). Letting geography fall where it may: Aerographies address the elemental. *Environment and Planning D: Society and Space*, 29(3), 435–444.
- Kindervater, K. H. (2017). Drone strikes, ephemeral sovereignty, and changing conceptions of territory. *Territory, Politics, Governance*, 5(2), 207–221.
- Kohler, R. E. (2011). History of field science: Trends and prospects. In J. Vetter (Ed.), *Knowing global environments: New historical perspectives on the field sciences* (pp. 212–240). New Brunswick, NJ: Rutgers University Press.
- Kohler, R. E., & Vetter, J. (2016). The field. In B. Lightman (Ed.), *A companion to the history of science* (pp. 282–295). Oxford, England: Wiley.
- Kuklick, H., & Kohler, R. E. (1996). Science in the field: Introduction. *Osiris*, 11, 1–14.
- Lallemand, C. (1891). L'unification des altitudes et le niveau des mers en Europe. In Association française pour l'avancement des sciences, *Compte rendu de la 19me session* (pp. 930–940). Paris, France: M. G. Masson.
- Latour, B. (2014). Some advantages of the notion of "critical zone" for geopolitics. *Procedia Earth and Planetary Science*, 10, 3–6.
- Le Gars, S., & Aubin, D. (2009). The elusive placelessness of the Mont-Blanc observatory (1893–1909): The social underpinnings of high-altitude observation. *Science in Context*, 22(3), 509–531.
- Livingstone, D. N. (2003). *Putting science in its place: Geographies of scientific knowledge*. Chicago, IL: University of Chicago Press.
- Mattes, J. (2020). National spaces and deepest places: Politics and practices of verticality in speleology. *Centauro*, 62(4), 670–696.
- McCormack, D. P. (2008). Engineering affective atmospheres: On the moving geographies of the 1897 Andree expedition. *Cultural Geographies*, 15, 413–430.
- McCormack, D. P. (2009). Aerostatic spacing: On things becoming lighter than air. *Transactions of the Institute of British Geographers*, 34(1), 25–41.
- McCormack, D. P. (2018). *Atmospheric things: On the allure of elemental envelopment*. Durham, NC: Duke University Press.
- Melo Zurita, M. d. L., & Munro, P. G. (2019). Voluminous territorialisation: Historical contestations over the Yucatan Peninsula's subterranean waterscape. *Geoforum*, 102, 38–47.



- Merchant, P. (2020). Verticalities in oral histories of science. *Centaurus*, 62(4), 783–796.
- Meusburger, P., Livingstone, D. N., & Jöns, H. (Eds.). (2010). *Geographies of science*. Heidelberg, Germany: Springer Verlag.
- Michel, B. (2019). Making Mount Kilimanjaro German: Nation building and heroic masculinity in the colonial geographies of Hans Meyer. *Transactions of the Institute of British Geographers*, 44(3), 493–508.
- Miéville, C. (2009). *The City and the City*. London, England: Macmillan.
- Millward, L. (2007). *Women in British Imperial airspace: 1922–1937*. Montreal, Canada: McGill-Queen's University Press.
- Minor, A. (2020). Up-and-down journeys: The making of Latin America's uniqueness for the study of cosmic rays. *Centaurus*, 62(4), 697–719.
- Mitman, G., Murphy, M., & Sellers, C. (2004). Introduction: A cloud over history. *Osiris*, 19, 1–17.
- Monmonier, M. S. (2008). *Coast lines: How mapmakers frame the world and chart environmental change*. Chicago, IL: University of Chicago Press.
- Moore, J. (2010). "This lofty mountain of silver could conquer the whole world": Potosí and the political ecology of underdevelopment, 1545–1800. *The Journal of Philosophical Economics*, 4(1), 58–103.
- Naylor, S. (2005). Introduction: Historical geographies of science: Places, contexts, cartographies. *The British Journal for the History of Science*, 38(1), 1–12.
- Naylor, S., & Ryan, J. R. (Eds.). (2010). *New spaces of exploration: Geographies of discovery in the twentieth century*. London, England: I. B. Tauris.
- Ophir, A., & Shapin, S. (1991). The place of knowledge: A methodological survey. *Science in Context*, 4(1), 3–21.
- Pérez, M. A. (2015). Exploring the vertical: Science and sociality in the field among cavers in Venezuela. *Social and Cultural Geography*, 16(2), 226–247.
- Pérez, M. A., & Melo Zurita, M. d. L. (2020). Underground exploration beyond state reach: Alternative volumetric territorial projects in Venezuela, Cuba, and Mexico. *Political Geography*, 79, 102144.
- Pommer, E. (Producer), & Lang, F. (Director). (1927). *Metropolis* [Motion picture]. Germany: UFA.
- Reidy, M. S. (2008). *Tides of history: Ocean science and Her Majesty's navy*. Chicago, IL: University of Chicago Press.
- Reidy, M. S. (2010). John Tyndall's vertical physics: From rock quarries to icy peaks. *Physics in Perspective*, 12(2), 122–145.
- Reidy, M. S. (2017). The most recent orogeny: Verticality and why mountains matter. *Historical Studies in the Natural Sciences*, 47(4), 578–587.
- Reidy, M. S. (2020). Darwin's vertical thinking: Mountains, mobility, and the imagination in 19th-century geology. *Centaurus*, 62(4), 631–646.
- Reidy, M. S., & Rozwadowski, H. M. (2014). The spaces in between: Science, ocean, empire. *Isis*, 105(2), 338–351.
- Rosol, C. (2015). Hauling data. Anthropocene analogues, paleoceanography and missing paradigm shifts. *Historical Social Research*, 40(2), 37–66.
- Rozwadowski, H. M. (2001). Technology and ocean-scape: Defining the deep sea in mid-nineteenth century. *History and Technology*, 17(3), 217–247.
- Rozwadowski, H. M. (2005). *Fathoming the ocean: The discovery and exploration of the deep sea*. Cambridge, MA: Belknap.
- Rupke, N. A. (1998). "The end of history" in the early picturing of geological time. *History of Science*, 36(1), 61–90.
- Sammler, K. G. (2019). The rising politics of sea level: Demarcating territory in a vertically relative world. *Territory, Politics, Governance*, June, 1–17. <http://dx.doi.org/10.1080/21622671.2019.1632219>.
- Schregel, S., Asciuto, N., & Engelhardt, N. (2020). Degrees of elevation – Modes of reflection. *Space and Culture*, March, 1–7. <http://dx.doi.org/10.1177/1206331219896985>.
- Shapin, S. (1998). Placing the view from nowhere: Historical and sociological problems in the location of science. *Transactions of the Institute of British Geographers*, 23(1), 5–12.
- Shaw, I. G. R. (2016). *Predator empire: Drone warfare and full spectrum dominance*. Minneapolis, MN: University of Minnesota Press.
- Simonetti, C. (2014). With the past under your feet: On the development of time concepts in archaeology. *Anuário Antropológico*, 2(December), 283–313.
- Simonetti, C. (2015). The stratification of time. *Time & Society*, 24(2), 139–162.
- Sloterdijk, P. (2016). *Foams: Plural spherology*. London, England: Semiotext(e).
- Smith, C., & Agar, J. (Eds.). (1998). *Making space for science*. London, England: Palgrave Macmillan.
- Steinberg, P. E. (2001). *The social construction of the ocean*. Cambridge, England: Cambridge University Press.
- Steinberg, P., & Peters, K. (2015). Wet ontologies, fluid spaces: Giving depth to volume through oceanic thinking. *Environment and Planning D: Society and Space*, 33(2), 247–264.
- Tucker, J. (1996). Voyages of discovery on oceans of air: Scientific observation and the image of science in an age of "balloonacy". *Osiris*, 11, 144–176.
- Vetter, J. (2011). Rocky Mountain high science: Teaching, research, and nature at field stations. In J. Vetter (Ed.), *Knowing global environments: New historical perspectives on the field sciences* (pp. 108–134). New Brunswick, NJ: Rutgers University Press.



- Vollset, M., Hornnes, R., & Ellingsen, G. (2018). *Calculating the world: The history of geophysics as seen from Bergen*. Bergen, Norway: Fagbokforlaget.
- Weizman, E. (2002, May 1). The politics of verticality. *Open Democracy*. Retrieved from [https://www.opendemocracy.net/en/article\\_801jsp/](https://www.opendemocracy.net/en/article_801jsp/)
- Weizman, E. (2007). *Hollow land: Israel's architecture of occupation*. London, England: Verso.
- Withers, C. W. J. (2009). Place and the "spatial turn" in geography and in history. *Journal of the History of Ideas*, 70(4), 637–658.
- Withers, C. W. J. (2017). *Zero degrees: Geographies of the prime meridian*. Cambridge, MA: Harvard University Press.
- Yusoff, K. (2013). The geoengine: Geoengineering and the geopolitics of planetary modification. *Environment and Planning A*, 45(12), 2799–2808.

**How to cite this article:** Hardenberg W. G. v., Mahony M. Introduction—Up, down, round and round: Verticalities in the history of science. *Centaurus*. 2020;62:595–611. <https://doi.org/10.1111/1600-0498.12347>